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POTENTIAL HIGH-CALCIUM LIMESTONE RESOURCES IN THE MOUNT JOY AREA, LANCASTER COUNTY, PENNSYLVANIA

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COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
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Pennsylvania Geological Survey

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PREFACE

The Bureau of Topographic and Geologic Survey within the Department of Environmental Resources is constantly interested in helping the mineral industries in the Commonwealth develop to their full potential. One of the ways in which the Bureau helps is by searching for occurrences of mineral resources that have a potential for economic development.

This information circular reports the discovery of a new occurrence of high-calcium limestone in Pennsylvania. The discovery is timely because recent forecasts indicate that the demand for this mineral commodity should increase. The demand will be even greater if the potential new market develops for its use in wet scrubbers to remove sulfur oxides from stack gases at power generating plants and at other industrial facilities that use coal.

This report should be of interest to active or potential producers and consumers of high-calcium limestone who are looking for exploration targets for this commodity. Land-use planners, local officials, as well as others in State and Federal agencies, private landowners, and educational institutions all will have use for the information in this report.

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POTENTIAL HIGH-CALCIUM LIMESTONE RESOURCES IN THE MOUNT JOY AREA, LANCASTER COUNTY, PENNSYLVANIA

by Bernard J. O'Neill, Jr.

ABSTRACT

Geologic mapping in the Mount Joy area, Lancaster County, Pennsylvania, disclosed the presence of high-calcium limestones believed to represent the Annville Formation. Structurally, the area lies within a zone of overturned folds, some of which are displaced in part by one of a series of imbricate thrust faults.

The Annville is a commercially valuable high-calcium limestone that is being quarried in parts of southeastern Pennsylvania. It is being used as a source for lime and flux stone in the steel industry, for chemical lime, for agricultural lime, and to enrich cement mix. Forecasts predict that the demand for high-calcium limestone will increase significantly once its use in the process for removing sulfur oxides from flue gases generated by steam-electric power plants is firmly established.

Chemical analyses of composite samples collected from an exposure representing 90 stratigraphic feet of Annville indicate that the $CaCO_3$ content averages 96.94 percent, and the $MgCO_3$ content averages 1.24 percent. The potential reserves of high-calcium limestone of the Annville in the mapped area, as roughly estimated, could exceed 30 million tons.

INTRODUCTION

The air-quality emission standards proposed by the Federal Environmental Protection Agency for steam-electric power plants have resulted in a number of research projects designed to develop processes capable of removing sulfur oxides from flue gases of plants burning high-sulfur fuels. The most advanced and promising process under consideration at the present time involves wet scrubbers that use lime or finely ground limestone which is high in calcium carbonate. Conservative estimates by Malhotra and Major (1974) indicate that widespread installation of flue-gas scrubbers, using lime or high-calcium limestone, will increase the existing demand for

these materials considerably. According to Malhotra and Major, if all electric power plants in Pennsylvania eventually use lime as the reactant in wet scrubber systems, the demand for lime will increase by more than 978,509 tons, or more than 43 percent over the 2,261,634 tons sold or used in this state in 1972. If, instead, high-calcium limestone is used, the demand for this commodity will increase by more than 1.7 million tons annually over the tonnage used or sold in Pennsylvania in 1972. Should these forecasts be anywhere near accurate, they undoubtedly will stimulate the search for high-calcium limestones which are currently being used as sources for lime and flux stone in the steel industry, for chemical lime, for agricultural lime, and to enrich cement mix.

To help satisfy the long-term demand for high-calcium limestone, the Pennsylvania Geological Survey is currently involved in a program of reexamining and, in some cases, remapping selected areas in the State where a potential for discovering deposits of high-calcium limestone exists. To date, some positive results have been achieved. The purpose of this paper is to report the results of mapping in the Mount Joy area of Lancaster County where high-calcium limestones of the Annville Formation are believed to be present.

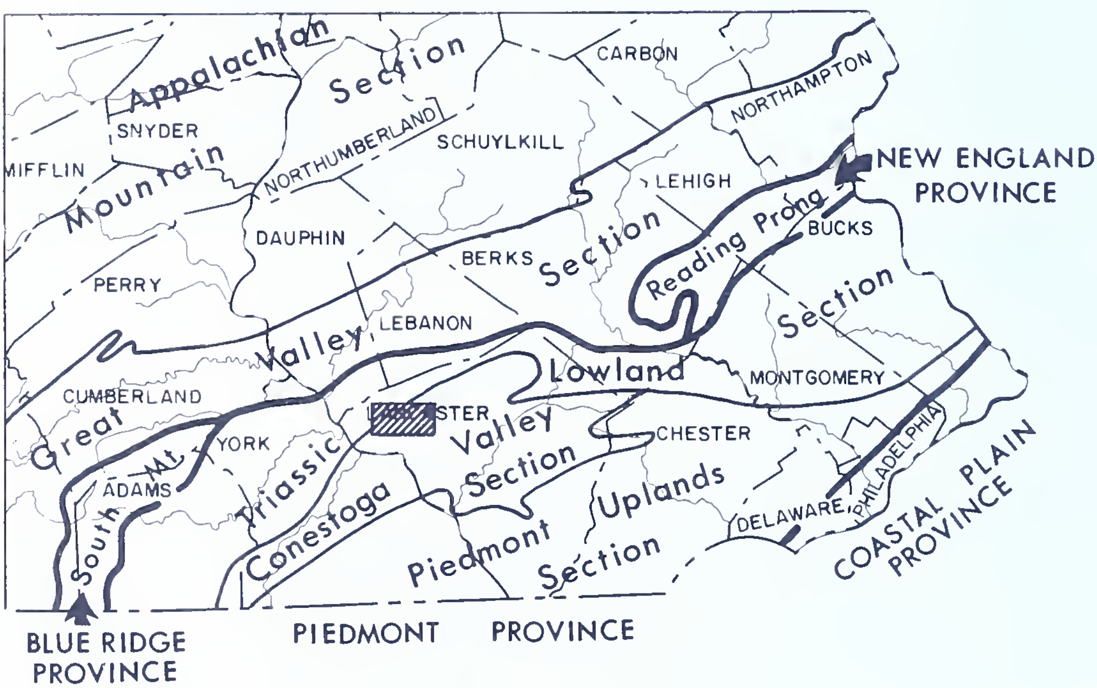

Figure 1. Physiographic provinces of southeastern Pennsylvania and location of the Mount Joy area.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The area is located north of the city of Mount Joy, in Mount Joy and Rapho Townships, Lancaster County, southeastern Pennsylvania (Figure 1). It measures approximately 10 square miles, and portions occur on the following 7½-minute quadrangles: Columbia East, Columbia West, Elizabethtown, and Manheim. Mount Joy, which has a population of less than 5000, is located about 22 miles southeast of Harrisburg, 11 miles northwest of Lancaster, and roughly 70 miles west-northwest of Philadelphia.

Most of the area lies within the Conestoga Valley of the Piedmont province, and is a lowland underlain mainly by shale and carbonate rocks of Ordovician age. Because they are more resistant to weathering and erosion, the shales form the higher hills which rise from 60 to 100 feet above the soluble carbonate rocks. Sandstone and shale of the Triassic Lowland occur near the northwestern border of the mapped area.

Little Chickies Creek is the principle stream draining the area. It flows generally south-southeast through the eastern part of the area, joining Chickies Creek about three miles south-southeast of Mount Joy. The waters from these streams discharge into the Susquehanna River near Chickies Rock, about 1½ miles northeast of Columbia, Pennsylvania.

STRATIGRAPHY

GENERAL

Field work in the Mount Joy area disclosed that rocks mapped as Beekmantown by Jonas and Stose (1930, 1933), and as the Epler Formation, a subdivision of the Beekmantown Group, by Meisler and Becher (1971), may include the Annville and Myerstown Formations. The Annville and Myerstown Formations of Middle Ordovician age are younger than rocks of the Beekmantown Group which are assigned to the Lower Ordovician. The presence of Annville limestone is of practical significance because of its economic potential as a source of high-calcium limestone.

The stratigraphic sequence of Ordovician age that occurs in the Mount Joy area includes the upper part of the Beekmantown Group and the Annville, Myerstown, and Cocalico Formations. Some clastic rocks of Triassic age occur in the northwestern part of the area (Plate 1). The formations underlying and overlying the Annville Formation are important because they serve as guides to the location of the high-calcium limestone in areas of limited exposure. Recognition of the Myerstown Formation in the Mount Joy area was directly responsible for selecting the area as an exploration target, because the Myerstown Formation commonly overlies the Annville Formation in the stratigraphic sequence. Descriptions of the

overlying and underlying formations are therefore included in the following sections.

ORDOVICIAN SYSTEM

Beekmantown Group

Lower Ordovician carbonate rocks of northern Lancaster County have long been assigned to the Beekmantown Group. Meisler and Becher (1971) have recognized that the Berks County subdivision (Hobson, 1957, 1963) is generally applicable to these rocks. Limestones with variable amounts of interbedded dolomite in the Mount Joy area belong to the upper part of the Beekmantown Group in the Epler Formation and possibly the uppermost Ontelaunee Formation.

A reference section of 110 feet of typical Epler Formation lithology in the Mount Joy area is described in the Appendix, section 1. This sequence consists of limestone zones ranging from 2 to 11 feet in thickness separated by dolomite zones ½ to 7 feet thick. The rock is generally medium light gray to dark gray, very finely to finely crystalline, and contains laminae such as shale partings or color bands. Beds range from ¼ inch to 3 feet in thickness. Secondary veinlets of white calcite are common.

Chert is not present at this reference section, but nodules and stringers of chert in float, not otherwise differentiable from float near the reference exposures, have been found in the Mount Joy area. This chert might mark the base of the Ontelaunee Formation, which is a conspicuously cherty zone in its type area. Wherever the Ontelaunee Formation has been distinguished it is more dolomitic than the underlying Epler Formation. Along its main exposure belt through the type area, however, the Ontelaunee ranges from essentially all dolomite at the Delaware River (Hobson, 1963) to portions having not much more dolomite than limestone near the Susquehanna River (MacLachlan, 1967). If this gradient has a southward component not evident along the Great Valley outcrop belt, the Ontelaunee Formation may well become entirely indistinguishable from the Epler Formation, at least under the poor exposure conditions prevailing in the Mount Joy area.

Post-Beekmantown erosion has been recognized from Berks County eastward, but not in Dauphin or Lebanon Counties immediately north of the Mount Joy area. In the former area a zone of dark pure dolomite forms the top of the Ontelaunee Formation immediately below the Annville Formation. In the Mount Joy area, the only exposure of the contact between the Beekmantown Group and the Annville Formation was found at location A (Plate 1) along Little Chickies Creek. Here, 19 feet of dolomitic limestone (about 6% $MgCO_3$) underlying the Annville (Appendix, section 2) is

clearly not like the upper Ontelaunee of Lebanon County. The difference may be the result of pre-Annville erosion or a lateral facies change. In any case, exposure conditions in the Mount Joy area do not permit differentiation of the Ontelaunee and Epler Formations, if the former is present.

Meisler and Becher (1971) refer all of these rocks to the Epler Formation and estimate a thickness of 2000 to 2500 feet in Lancaster County. This thickness is quite consistent with regional gradients of the combined Ontelaunee and Epler Formations of the Great Valley. Because a detailed stratigraphic study may yet show these formations to be divisible, it seems preferable to identify the rocks of the Mount Joy area as Upper Beekmantown Group undifferentiated.

Annville Formation

The Annville Formation is defined as the sequence of high-calcium limestones that directly overlies the Upper Beekmantown Group. Stratigraphically overlying the Annville is the Myerstown Formation. Prouty (1951) correlated the Annville Formation with the lower part of the Black River Group of Middle Ordovician age on the basis of stratigraphic position and lithology.

The Annville Formation was named for the town of Annville, Pennsylvania, located in the general area of the important high-calcium limestone industry. The type section was selected from the Bethlehem Mines Company quarry located about 1.5 miles northeast of Palmyra.

Only two exposures of limestones in the Annville Formation were found in the Mount Joy area. The best exposure is located along Little Chickies Creek (location A, Plate 1), where at least 90 feet of high-calcium Annville limestone occurs (Appendix, seetion 2). Limestones of the Annville Formation are also exposed at the north end of an abandoned quarry (location B, Plate 1), where an interrupted sequence of beds occurs in a stratigraphic interval measuring 15 feet in thickness (Appendix, section 3).

The only other evidence for the Annville Formation in the area is the presence of "Annville-like" boulders in rock piles or along fences and fragments of float in the soil.

The formation consists of medium-light- to dark-gray, dense- to coarse-crystalline limestones. In general, beds range in thickness from 6 inches to several feet. The lower part is distinguished from the remainder of the formation by the presence of beds of coarsely crystalline limestone.

Surfaces of weathered limestones are commonly light gray. A phenomenon often observed in the Annville is a type of differential weathering whereby fine laminae weather faster than the general surface of the outcrop, forming minute depressions to give a fluted appearance.

The thickness of the Annville Formation as measured at the exposure along Little Chickies Creek (location A, Plate 1, and Appendix, section 2)

is 90 feet. Further thickness determinations of the Annville Formation will require removal of overburden or core drilling.

Myerstown Formation

The Myerstown Formation stratigraphically overlies the Annville Formation, and Prouty (1959, p. 17-19) assigned it to the Middle Ordovician. In Lebanon County, the Myerstown Formation is overlain by the Hershey Formation, which largely disappears westward into Dauphin County and may similarly pinch out to the south. No evidence was found to indicate the presence of the Hershey Formation in the Mount Joy area. Here the Cocalico Formation overlies the Myerstown Formation, but no exposure showing the contact relationship between these units was observed. The Myerstown Formation was named from exposures in the general vicinity of Myerstown, Lebanon County, Pennsylvania.

The Myerstown Formation consists in general of medium-dark-gray, dense- to finely crystalline, thin-bedded limestones. Beds range in thickness from 1/4 inch to a maximum of 4 inches. When weathered, they tend to break down to form thin slabs. These slabs give a ringing sound when struck with a hammer due to the dense, compact texture of the limestone. This characteristic is extremely helpful when identifying the Myerstown.

The best exposures of the Myerstown in the Mount Joy area are: (1) in an abandoned quarry about 3000 feet north of the Post Office in Mount Joy (location B, Plate 1), where more than 50 feet of the Myerstown Formation is exposed (Appendix, section 3); (2) along Little Chickies Creek in both an east and south direction from the abandoned quarry mentioned above; and (3) at the north end of the exposure along the west bank of Little Chickies Creek about 8500 feet north of the Post Office in Mount Joy (location A, Plate 1). Two samples of limestones, tentatively assigned to the Myerstown, were collected at the latter exposure. They represent 19 stratigraphic feet of section and are high-calcium in composition. These samples, identified as H and I in Table 1, contain 97.17 and 96.24 percent $CaCO_3$, respectively.

Although the total thickness of the Myerstown could not be accurately determined in the Mount Joy area, Meisler and Becher (1971, p. 26) report it to be about 200 feet thick in Lancaster County.

Contact with the underlying Annville Formation is apparently concordant, and the presence of the Myerstown was therefore used as a guide in field exploration.

Cocalico Formation

The Cocalico Formation was not studied in detail. Most commonly, exposures of it are weathered to soft, buff to yellow shale. Fresh exposures, however, usually show dark-gray shale. Dense white quartz fragments are abundant in the shale float.

Table 1. *Chemical Analyses of Limestones from the Annville Formation, the Myerstown Formation, and the Upper Beekmantown Group in the Mount Joy Area, Lancaster County, Pennsylvania*

	Geologic unit					Sample represents			Chemical analyses (Done in Pa. Dept. Transportation laboratories)						Calculation of calcium and magnesium oxides as carbonates[2]	
Location–Plate 1	Annville Formation	Myerstown Formation	Upper Beekmantown Group	Sample identification[1]	Thickness of unit (in feet)	Exposure	Float	Boulder pile	CaO	MgO	SiO_2	R_2O_3	LOI	Total	$CaCO_3$	$MgCO_3$
A			X	A	19	X			52.34	2.92	1.54	0.40	43.46	100.66	91.47	6.0
A	X			B	10	X			57.89	0.89	0.60	0.42	42.71	102.51	94.80	1.71
A	X			B′	8	X			55.10	1.10	0.60	0.36	43.53	100.69	96.07	2.26
A	X			C	19	X			56.00	0.55	1.56	0.68	43.41	102.20	97.19	1.13
A					15	(Covered area)										
A	X			D	12	X			55.92	0.59	0.78	0.50	43.71	101.50	97.54	1.21
A	X			E	10	X			56.66	0.66	0.60	0.66	43.48	99.06	96.81	1.32
A	X			F	10	X			56.66	None	1.44	0.48	43.50	102.08	98.63	None
A	X			G	6	X			56.27	0.71	0.84	0.82	43.49	102.13	97.15	1.44
A	Average for 90 feet of section (samples B through G)										1.0	0.56			96.94	1.24
A		X		H	5	X			55.14	0.54	0.88	0.32	43.48	100.36	97.17	1.11
A		X		I	14	X			55.74	0.75	1.10	0.40	43.33	101.32	96.24	1.53
A′	X			1	—		X		55.72	0.63	0.96	0.66	43.56	101.53	97.21	1.30
A′	X			2	—			X	55.72	0.75	1.08	0.44	43.52	101.51	96.90	1.53
A′	X			3	—		X		54.72	1.24	1.68	0.62	43.16	101.42	94.87	2.53
B	X			1	15	X			56.86	0.72	0.70	0.80	43.30	99.38	96.55	1.44
D	X			1	—			X	55.96	None	1.52	0.84	42.95	101.27	97.42	None

[1] Refer to Appendix, section 2, for descriptions of intervals of limestone represented in samples A through I.

[2] The percentages of carbonates were calculated utilizing all of the LOI shown in the chemical analyses as CO_2.

TRIASSIC SYSTEM

Triassic sandstone and shale overlap the rocks of Ordovician age in the northwestern part of the area (Plate 1). These were not studied in detail. The interested reader is referred to Jonas and Stose (1933) for descriptions of these rocks.

STRUCTURE

GENERAL

Interpretations of geologic structures are important in prospecting for, and estimating, reserves of high-calcium limestone in the Mount Joy area. Although the structure is complex, the interpretations presented here are believed to be essentially correct. However, further information obtained during drilling will undoubtedly modify them to some extent.

Structurally, the Mount Joy area lies within a zone of overturned folds, some of which are displaced in part by one of a series of imbricate thrust faults, all of which occur in the troughs of synclines (cross section, Plate 1). Although many details of the folding and faulting are probably missing, the cross section illustrates the apparent major structures.

DESCRIPTIONS OF STRUCTURES

Mount Pleasant Anticline

The Mount Pleasant anticline is the northernmost structure in the area (Plate 1) and, as shown in the cross section, is interpreted to be overturned to the north. It is cut by a high-angle reverse fault which strikes east-west. Carbonate rocks of the Upper Beekmantown Group are brought to the surface on the upthrown side of the fault where the shales of the Cocalico Formation have been breached. The structural relationship of the Cocalico and Upper Beekmantown is not clear here. However, the absence of the Annville and Myerstown Formations in the stratigraphic sequence indicates that either an unconformity or a thrust fault exists between the Cocalico and Upper Beekmantown. The interpretation illustrated on Plate 1 is that of the unconformity.

The possibility that high-calcium limestones of the Annville Formation are present in portions of the Mount Pleasant anticline should not be overlooked. Erosion associated with the unconformity or displacement caused by thrust faulting could account for the absence of Annville limestones in surface exposures. As shown in the cross section (Plate 1), exploration targets for the Annville exist on both limbs and at the apex of the Mount Pleasant anticline. Because these "blind" targets are based on speculation rather than direct evidence, they are assigned a lower priority than others in the area.

Mount Pleasant Syncline

The Mount Pleasant syncline is an overturned isoclinal fold. It is overturned to the north, and both limbs dip moderately to the south. As shown in the cross section on Plate 1, a low-angle thrust fault—the North thrust—dips south and is interpreted to occur within the trough of the syncline. At the surface it is shown to occur at the southern border of Cocalico shales in the northern part of the area.

The Mount Pleasant syncline is especially important because the best exposures of high-calcium limestones in the Annville Formation within the Mount Joy area occur in its southern limb along Little Chickies Creek at location A (Plate 1). The chemical analyses from this seetion in Table 1 show that the percentage of calcium earbonate in the Annville ranges from 94.8 to 98.63, and the magnesium carbonate content ranges from 0 to 2.26 percent.

A high-priority exploration target for Annville limestones is along strike of the exposure at location A. A north-oriented angle hole collared south of the suggested outcrop line shown on Plate 1 could serve a dual purpose because: (1) it should penetrate and therefore eonfirm the down-dip extension of the Annville in the south limb of the Mount Pleasant syncline, and (2) if successful in (1), deeper drilling in the same hole could test for the Annville Formation postulated to exist in the upright north limb of the Mount Pleasant syncline.

Mapping the Annville Formation along strike of the exposures at location A was done primarily by reeognition of rocks of the Myerstown Formation present as float or in exposures. The limestones of the Annville Formation are apparently partieularly susceptible to weathering, and henee easily masked or covered during the process of erosion.

Bonanza Anticline

The Bonanza anticline is an overturned fold that appears to be a subsidiary fold to the Mount Pleasant anticline. Unlike the Mount Pleasant anticline, erosion has stripped off a greater portion of this fold, as shown diagrammatically in the cross seetion on Plate 1.

The overturned north limb of the Bonanza anticline is also the south limb of the Mount Pleasant syncline, which was described and classified previously as an excellent exploration target.

The southern limb of the Bonanza anticline dips moderately south-southeast at about 20 to 30 degrees (Plate 1). The Annville Formation is not exposed along this limb. However, exposures and float of the Myerstown Formation suggest the possibility that high-calcium limestones of the Annville Formation are present but eoncealed. As shown in the cross section, the Annville Formation should occur directly beneath the Myerstown Formation in the down-dip extension of the south limb of the Bonanza

anticline. Because of the complex structure, it is possible that an unmapped thrust fault cuts out the Annville below the Myerstown. Although this alternative cannot be ruled out, no evidence for a thrust fault at this position was found during the field work. Drilling and/or trenching is recommended to determine the presence of the Annville in the southern limb of the Bonanza anticline. Vertical or angle holes (oriented north-northwest) should be collared in the basal part (northern part) of the Myerstown Formation to penetrate the Annville Formation in this limb.

Florin Syncline

The Florin syncline lies immediately south of the Bonanza anticline; its north limb is common to the south limb of the anticline (Plate 1). The structural model in the cross section shows that the north limb of the Florin syncline dips moderately to the south to a postulated depth of about 700 feet, where it bends to form the trough of the syncline. At some place within this trough, the Middle thrust fault cuts through to move the rocks in the overthrust plate or hanging-wall side of the fault closer to the surface.

Some recommendations for exploratory drilling in the north limb of the Florin syncline are covered in the preceding section on the Bonanza anticline; ideas covering the south limb of the syncline appear in the following section on the Prospector's anticline.

Prospector's Anticline

The Prospector's anticline is a subsidiary fold to the larger Bonanza anticline, as shown in the cross section (Plate 1). It is an important structure because it brings limestones of the Annville Formation to the surface. Flanked to the north by the Middle thrust fault and to the south by the South thrust fault, the Prospector's anticline is located within the most complex structural environment in the area (Plate 1). The South thrust fault covers the westward extension of the Prospector's anticline, hence the possibility that limestones of the Annville Formation extend under this part of the thrust should not be overlooked.

Samples of Annville limestone were collected from an exposure north of an abandoned quarry at location B and from large slabs found along a fence line at location D (Plate 1). The chemical analyses for these samples show the calcium carbonate content to be 96.55 percent and 97.42 percent, respectively (Table 1).

It is recommended that angle holes, oriented north-northwest and collared in the Myerstown Formation in the south limb of the Prospector's anticline, be drilled to sufficient depth to test for the Annville Formation in both limbs of the structure.

ECONOMIC CONSIDERATIONS

CHEMICAL ANALYSES

The sampling program in the Mount Joy area was primarily limited to the available exposures, float, and rock piles of limestones of the Annville Formation and adjacent units. The program therefore is considered to be less extensive than desired, but certainly good enough to provide a reasonable preliminary measure of the quality of the stone. Full commercial evaluation will require extensive diamond drilling to provide more detailed information about: (1) the quality and reserves; (2) geologic structure; and (3) ground-water conditions that will affect quarrying and/or underground mining.

Chemical analyses for 15 samples appear in Table 1. Twelve of these represent limestones in the Annville Formation; two represent limestones in the Myerstown Formation; and the remaining sample represents an interval of the Upper Beekmantown Group which stratigraphically lies directly below the base of the Annville Formation. Eight of the Annville samples were collected from exposures, two from float, and the remaining two from boulder piles. The two samples representing the lower part of the Myerstown Formation, as well as the sample from the Upper Beekmantown Group, were collected from exposures.

The eleven samples collected from exposures are representative composite samples of equal-volume fragments taken at 6-inch intervals across the stratigraphic thicknesses shown in Table 1. The two float samples represent equal-volume fragments taken at 5-foot intervals along traverses oriented at right angles to the strike of the beds. The two samples from boulder piles are classified as grab samples.

The chemical analyses were done in the laboratory of the Pennsylvania Department of Transportation in Harrisburg, Pennsylvania. The fragments in each sample were crushed, ground, split, and analyzed to determine chemical composition. The oxides were determined by wet chemical analyses; the volatile fraction was determined by loss of weight after heating to 1000°C. The results of these analyses are shown in Table 1. A calcium and magnesium carbonate content for each sample was calculated assuming all of the LOI (loss on ignition) shown in the chemical analyses represents CO_2. In every sample, insufficient LOI is present to convert all of the CaO and MgO to carbonates.

Samples identified as B through G at location A (Table 1; Plate 1) represent a stratigraphic interval of the Annville Formation which measures 90 feet. The weighted averages of $CaCO_3$ and $MgCO_3$ as calculated for this interval are 96.94 percent and 1.24 percent, respectively. The range of $CaCO_3$ for samples within this interval is 94.8 to 98.63 percent, and the $MgCO_3$ content ranges from 0 to 2.26 percent.

The calculated carbonate contents for the remaining samples of Annville that were collected at locations B and D (Plate 1; Table 1) are 96.55 and 97.42 percent, with the $MgCO_3$ contents at 1.44 and 0 percent, respectively.

All analyses indicate that the Annville Formation is a potential source of high-calcium limestone in the Mount Joy area.

RESERVES

Any calculation of the reserves of high-calcium Annville limestone in the Mount Joy area is risky at this time because of the complex geology that must be confirmed by diamond drilling. However, in order to understand the potential magnitude of reserves, a rapid calculation was made using the following assumptions:

1. The Annville Formation is present as mapped at the surface.
2. Average stratigraphic thickness of the Annville is 90 feet.
3. It is quarryable or mineable downdip for a distance of 100 feet.
4. Twelve cubic feet of limestone equals one ton.

Based on these factors, the potential reserves of high-calcium limestone in the Annville Formation in the Mount Joy area are estimated to be more than 30 million tons.

CONCLUSIONS

Analyses of samples from the Annville Formation indicate an average $CaCO_3$ content close to the desired composition of commercial-grade high-calcium limestone. Potential reserves of Annville in the Mount Joy area are estimated to be large. Full commercial evaluation will require extensive diamond drilling to confirm the quality and quantity of the stone.

ACKNOWLEDGMENTS

Dr. Marvin E. Kauffman, Chairman of the Department of Geology at Franklin and Marshall College in Lancaster, Pennsylvania, kindly made available student theses dealing with geologic studies in Lancaster County; these, in combination with State and Federal publications, were useful in selecting the best possible exploration targets for the Annville Formation.

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of the Pennsylvania Geological Survey. John G. Kuchinski of the Pennsylvania Geological Survey drafted the figure and plate.

R. Davidson and M. J. Coldsmith of the Pennsylvania Department of Transportation facilitated the early release of this report by scheduling and performing the chemical analyses.

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APPENDIX

MEASURED SECTIONS

Section 1

Inactive quarry approximately 2000 feet northeast of Mt. Pleasant Church. Section starts with exposures at ground elevation north of the quarry faces and continues stratigraphically down into the older beds exposed in the quarry faces. Section measured by Russell W. Pfeil, Jr.

	Thickness in feet Unit	*Formation total*
Upper Beekmantown Group—probably Epler Formation		
Exposures at ground level		
Limestone, dark-gray, finely crystalline; occasional lamination; weathers medium to light gray; breaks into blocky fragments.	4.5	4.5
Dolomite, interbedded medium- and dark-gray, very finely crystalline with silty texture; beds average ¼ in. in thickness; weathers light gray; blocky fracture system.	0.5	5.0
Limestone, predominantly dark- and medium-gray but pinkish caste in places; banded (bands ¼ to 1½ in. thick); fine to medium crystalline; numerous veins of calcite; weathers medium to light gray; blocky fracture system.	1.5	6.5
Limestone, grayish-black to medium-gray, finely crystalline, slightly laminated; weathers medium dark gray to light gray; blocky fracture system.	1.0	7.5
Limestone, medium-light- and dark-gray, finely crystalline, banded (bands ½ to 1 in. thick); weathers olive gray to medium dark gray.	1.0	8.5
Dolomite, medium-dark-gray, laminated; silty texture; contains veins and nodules of calcite and well-developed needle-like quartz in veins; semi-blocky fracture system; weathers light gray.	2.5	11.0
Limestone, grayish-black and medium-dark-gray, finely crystalline, banded throughout, laminated in part; bands ¼ to 1 in. thick; weathers medium to light gray with rough surfaces.	2.5	13.5
Covered interval.	20.0	33.5
(Section continued below with northernmost exposure in west face of quarry.)		
Limestone, medium-dark-gray, finely crystalline, weathers medium light gray.	2.0	35.5
Limestone, laminated; algae zone.	1.5	37.0
Limestone, breccia and banded breccia zone.	2.0	39.0
Limestone, medium-dark-gray, finely crystalline, massive; weathers medium light gray.	3.0	42.0
Dolomite, dark-gray, finely crystalline, slightly laminated; weathers medium gray to tan; blocky fracture system.	1.0	43.0

	Thickness in feet Unit	Formation total
Limestone, dark-gray, finely crystalline, massive, slightly shaly with a platy fracture; weathers mottled medium light gray.	2.0	45.0
Dolomite, dark-gray, finely crystalline, slightly laminated; weathers light olive gray; blocky fracture.	1.5	46.5
Limestone, medium-dark-gray, finely crystalline; algal structures in upper part; some shaly partings; weathers medium dark gray.	8.0	54.5
Dolomite, dark-gray, slightly laminated; weathers medium light gray to light olive gray.	4.0	58.5
Limestone, dark-gray, finely crystalline, slightly laminated in part; weathers medium gray; blocky fracture.	11.0	69.5
Dolomite, dark-gray, slightly laminated; weathers medium light gray.	2.0	71.5
Limestone, dark-gray, finely crystalline, laminated in part, carbonaceous in part; en-echelon gash veins of calcite; weathers dark gray; blocky fracture.	7.0	78.5
Dolomite, gray-black, finely crystalline; weathers medium dark gray; blocky fracture.	3.5	82.0
Limestone, dark-gray, finely crystalline, massive; weathers medium to dark gray.	3.0	85.0
Dolomite, medium-dark-gray, finely crystalline, slightly laminated; weathers medium light gray.	7.0	92.0
Limestone, dark-gray, finely crystalline, laminated, weathers medium to dark gray.	3.0	95.0
Dolomite, dark-gray, finely crystalline, laminated in part; weathers medium gray; blocky.	7.0	102.0
Limestone, dark-gray, finely crystalline, slightly laminated in part; weathers medium light gray; blocky.	8.0	110.0

Section 2

Section along the bank of Little Chickies Creek, 8500 feet north of the Post Office in Mount Joy (location A, Plate 1). Descriptions start at southern part of exposure and continue northward through progressively younger beds. Section measured by Russell W. Pfeil, Jr., and B. J. O'Neill, Jr.

*Sample identification**		*Thickness in feet Unit*	*Formation total*
Upper Beekmantown Group			
A	Dolomitic limestone, medium- to dark-gray, dense; massive beds; weathers to tan- and buff-colored blocky fragments.	19	19
	Total Upper Beekmantown		19

		Thickness in feet	
		Unit	*Formation total*
Annville Formation			
B	Limestone, medium-dark- to dark-gray, finely crystalline with a sugary texture that becomes apparent when the rock is etched with HCl. Beds are 6 in. to 2 ft thick. Weathers light gray. A few calcite veinlets.	10	10
B′	Limestone, medium-dark- to dark-gray, coarse-crystalline; massive beds up to 2 ft thick; banding present in some beds; weathers light gray. Some calcite veins with limonite (?) staining.	8	18
C	Limestone, medium-light- to medium-gray, fine- to coarsely crystalline, weathers light gray; some calcite veinlets.	19	37
	Covered interval.	15	52
D	Limestone, medium- to dark-gray, dense- to finely crystalline; silty to smooth texture; massive beds up to several feet thick; numerous calcite veins and some carbonaceous material; weathers light gray.	12	64
E	Limestone, medium- to dark-gray; dense, massive beds up to several feet thick; weathers light gray, few calcite veins.	10	74
F	Limestone, medium- to dark-gray; dense, massive beds ranging from 6 to 24 in. thick; platy and banded beds present; carbonaceous in places; few calcite veins; weathers light gray.	10	84
G	Limestone, medium-light- to medium-gray, dense- to very finely crystalline; massive beds ranging from 6 to 12 in. in thickness; platy structure with some carbonaceous material evident. Few calcite veins, weathers light gray.	6	90
	Total Annville Formation		90
	Myerstown (?) Formation		
H	Limestone, medium- to medium-dark-gray, dense- to finely crystalline; platy, but carbonaceous material and calcite veins absent; weathers light gray. Possibly Myerstown Formation or transitional phase of Annville Formation to Myerstown Formation.	5	5
I	Limestone, medium-light- to medium-dark-gray; dense, platy structure with plates ranging from 1/4 to 3 in. in thickness; carbonaceous material is more concentrated in darker plates; calcite veins present; weathers light gray. Possibly Myerstown Formation or part of transitional phase from Annville Formation to Myerstown Formation.	14	19
	Total Myerstown (?) Formation		19

(End of exposed section)

*Refer to Table 1 for chemical analyses of sample.

Section 3

Abandoned quarry approximately 3000 feet north of the Post Office in Mount Joy. Descriptions start from top of quarry and continue down through progressively older beds. Section measured by Russell W. Pfeil, Jr.

	Thickness in feet Unit	*Formation total*
Myerstown Formation		
Soil cover.	2	2
Limestone with few dolomitic beds, medium-dark-gray, finely crystalline, thin-bedded (¼ to 1½ in. thick); silty partings (1 mm thick) common; fractures into platy fragments; calcite eyes rare but present; weathers medium gray.	3.5	5.5
Limestone, medium-light-gray, finely crystalline, thin-bedded (½ to 2 in. thick), banded; breaks into platy fragments; crossbedding common; weathers to olive brown and medium dark gray.	1.1	6.6
Limestone, dark-gray, finely crystalline; laminated with stringers and patches of calcarenite; crossbedding, carbonaceous material, and shaly partings common; chert nodules occur in 2-in.-thick bed about 2 ft below the top of this unit; weathers light gray.	14.0	20.6
Limestone, dark-gray, finely crystalline, carbonaceous with shaly partings; beds up to 4 in. thick; bottom foot has well-developed laminae showing crossbedding; not as platy as preceding part of section; weathers to mottled medium light gray and olive gray.	5	25.6
Limestone, dark-gray, finely crystalline, moderately thick beds (2 to 3 in.) with silty shale partings; bottom ½ ft has well-developed crossbedding; platy character lacking; weathers medium gray.	6.5	32.1
Limestone, dark-gray, finely crystalline, well laminated with beds ranging from ¼ to 4 in. in thickness; slightly platy; weathers medium light gray.	7.0	39.1
Limestone, dark-gray, fine- to medium-crystalline; moderately bedded, few laminations; weathers medium light to medium dark gray.	15.0	54.1
Cover.	4.0	58.1
Annville Formation		
Limestone, dark-gray, coarsely crystalline; massive beds, weathers light gray with fluted surfaces.	15.0	15.0
Total thickness of all units		73.1